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Title: Module 4 Hand-Stacking and Remote Approach to Critical Using the Planet/Comet Assembly

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Intended for: This presentation will be used as part of the training that students get when they take the Nuclear Criticality Safety Class in Nevada.

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NUCLEAR CRITICALITY SAFETY PROGRAM

Module 4
Hand-Stacking and Remote Approach to Critical Using the Planet/Comet Assembly

Unclassified
LA-UR-21

Prepared by Rene Sanchez, Travis Grove, and Theresa Cutler

Goals

- To ensure students gain a working knowledge of how to apply the "½-way " and "¾" safety rules for performing a "hand-stack" operation.

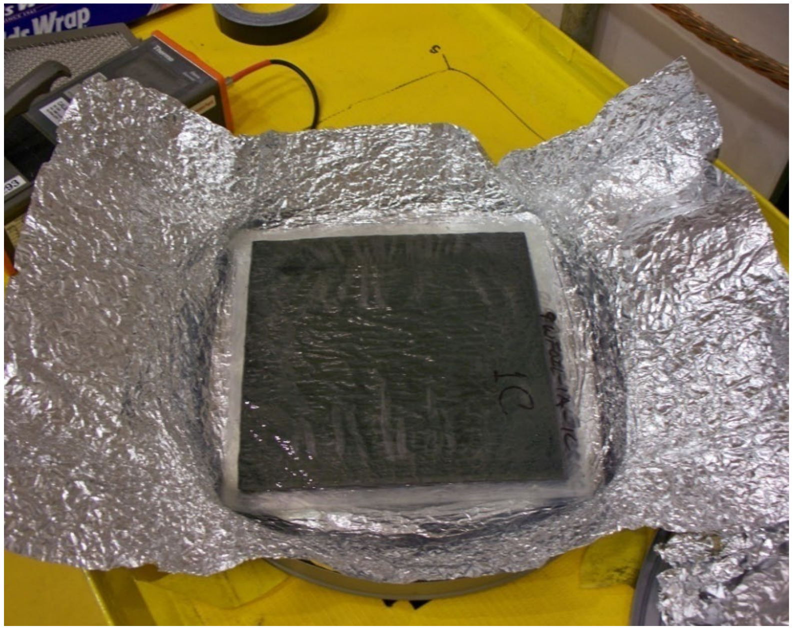
- To ensure students gain a working knowledge of how changes in moderator and reflector geometry affect the criticality of a system.

- To ensure students gain experience using the Inhour equation relating reactivity and reactor period.

Module 4
Part 1: Hand-Stacking

What Do We Want To Do?

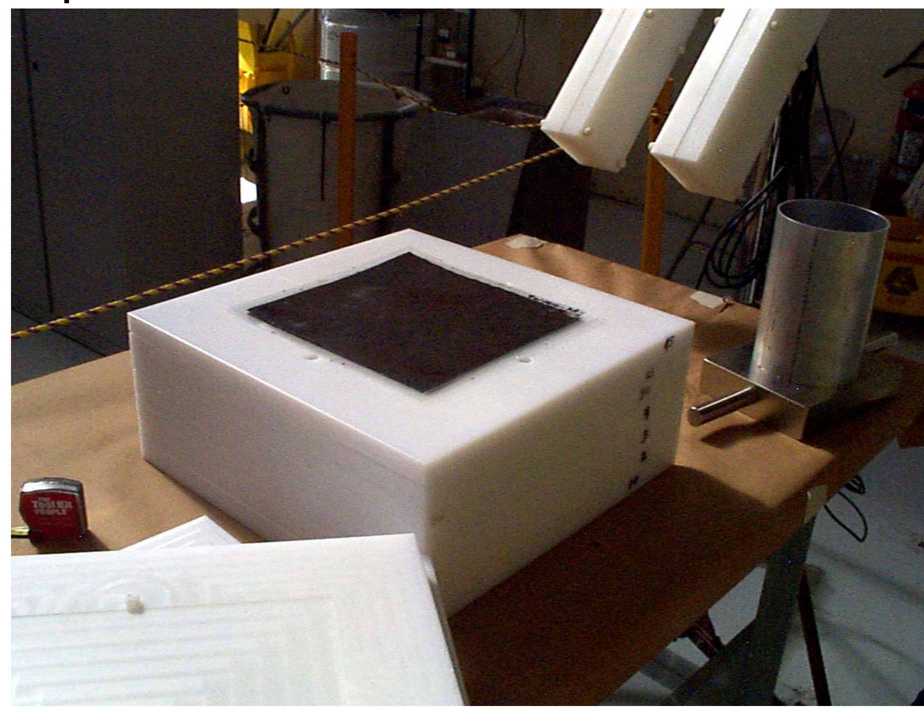
Demonstrate Moderation



- The poly/lucite plates act as a moderator and reflector
  - Lots of hydrogen, a good moderator!
  - Mimics a fissile solution system

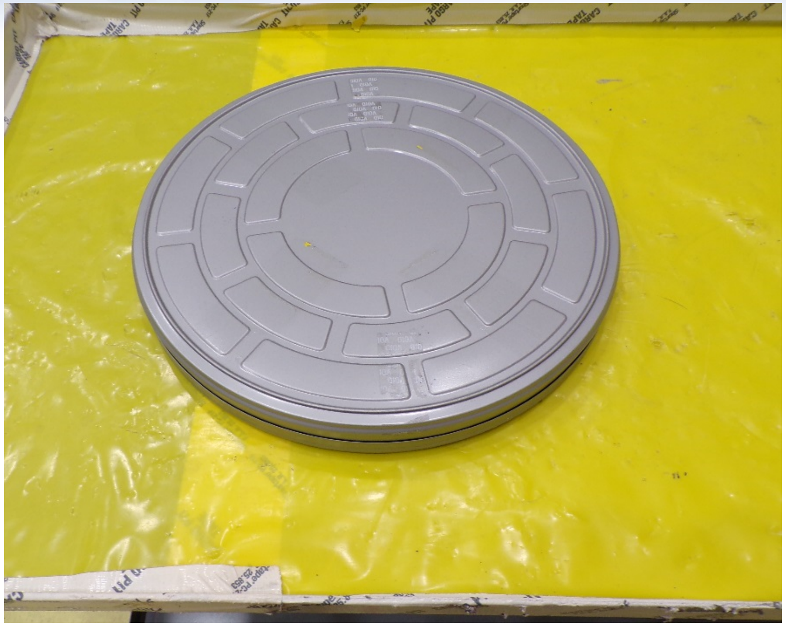
HOW?

We want to interleave thin HEU foils in between polyethylene/Lucite plates



HDP H density 123% of H_2O
Lucite H density 85% of H_2O

Class Foils (HEU)



Uranium Metal Foils
9.0-in square by 0.003-in thick

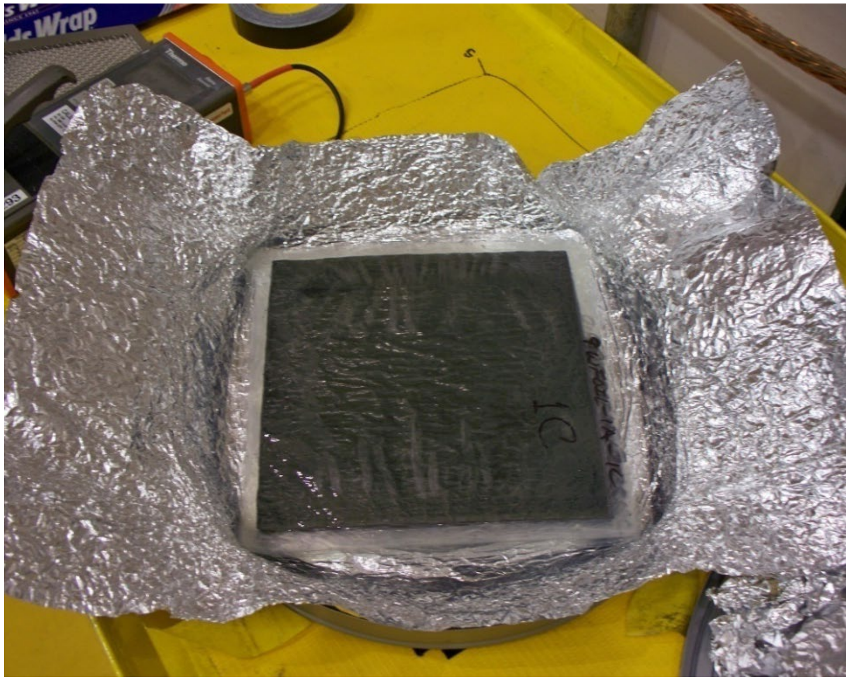
Starting with foils in a Can
Mass per foil: ~70 g
Total number of foils: 26
Total Mass in Can: ~1,800 g

93.19 wt% ^{235}U
Average Density: 17.25 g/cc

^{235}U metal mass limit in CSED: 10,000 g

Why are we ok at the start, if we know we have enough material to go prompt critical?

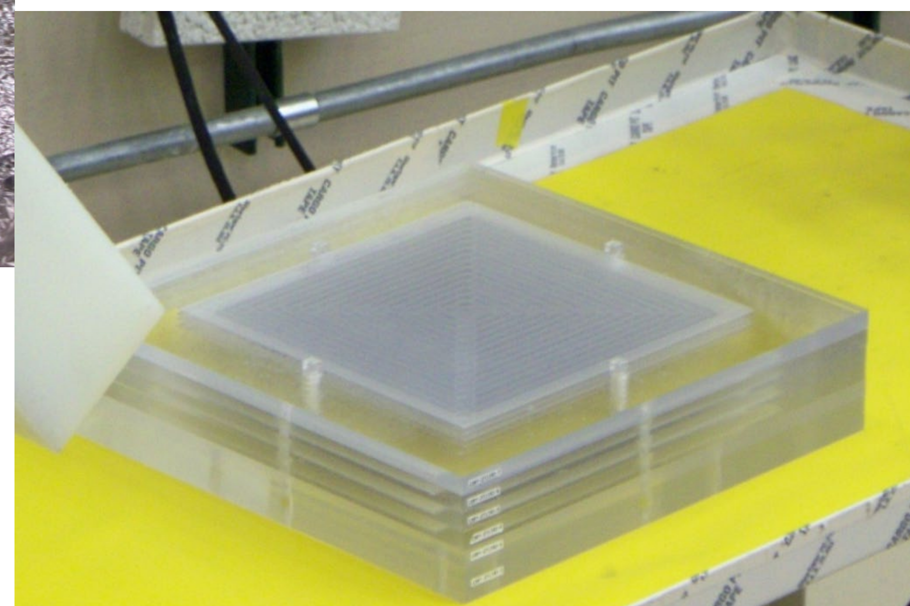
Class Foil Experiment



Fuel units consist of

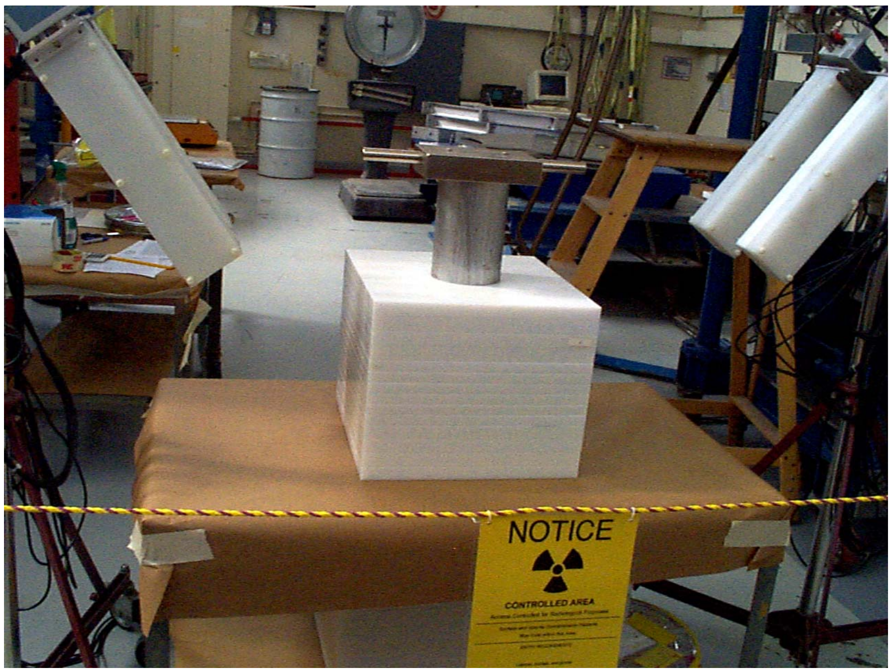
laminated uranium metal foils and polyethylene or lucite plates

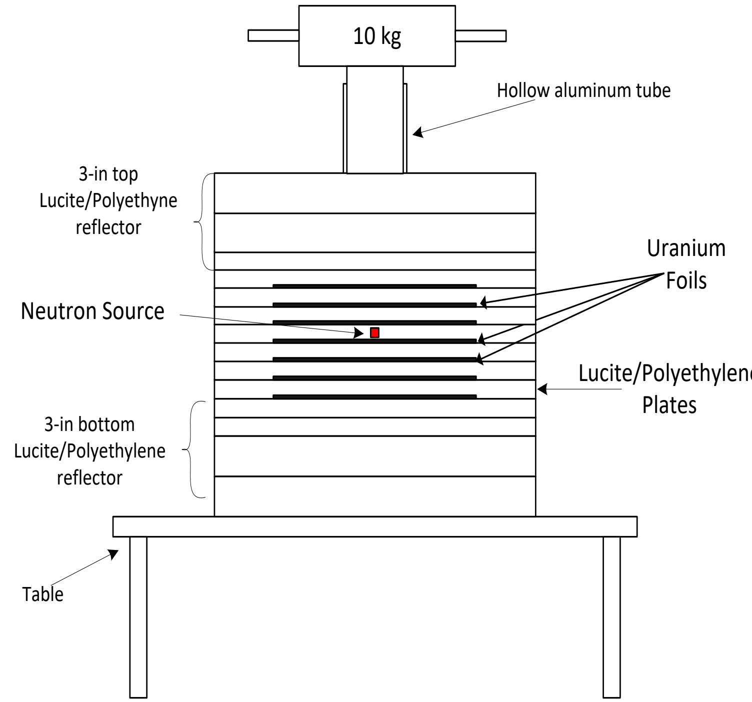
If we stack enough foil-lucite/poly plate units together, we will achieve a critical configuration



Handstacking

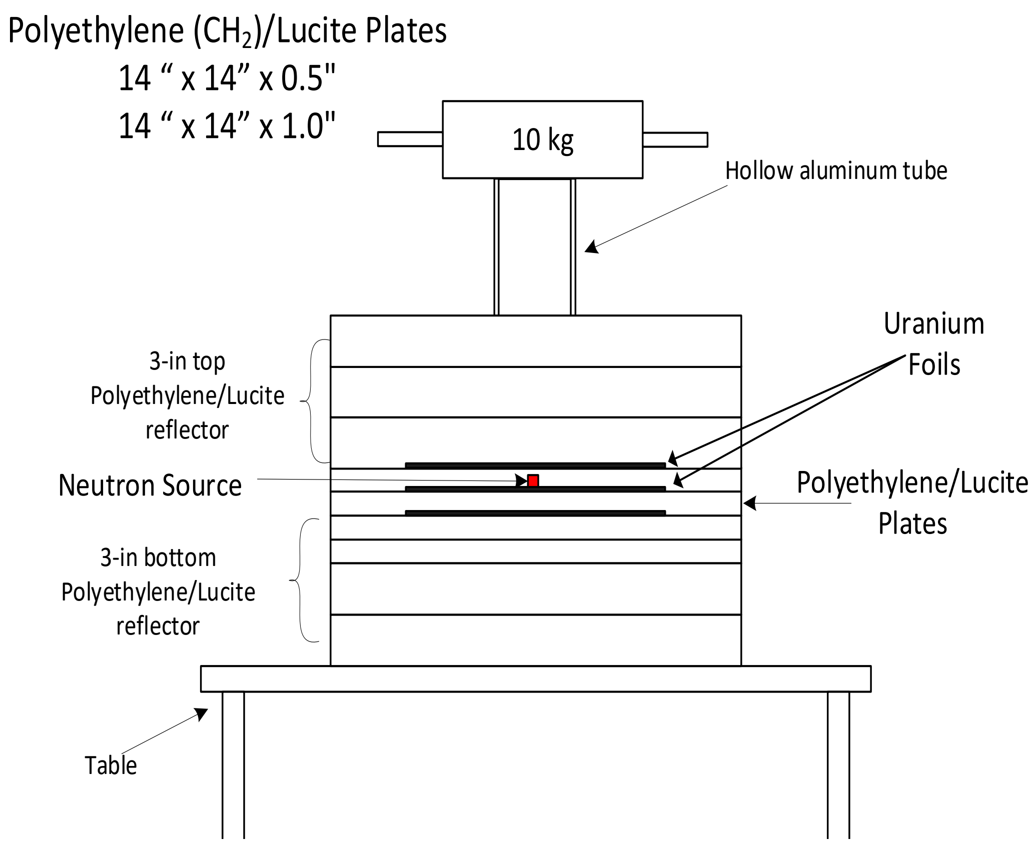
If we stack enough foil-poly/lucite plate units together, we will achieve a critical configuration





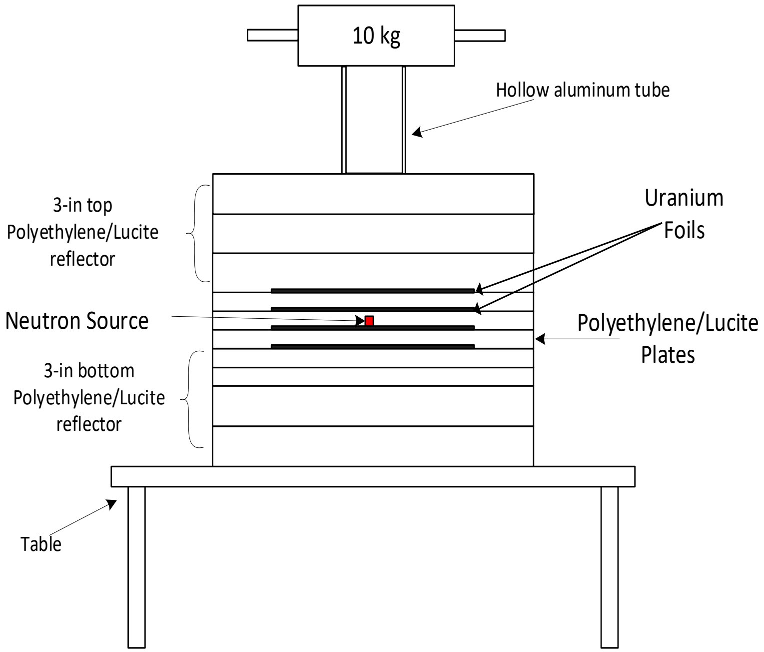
- Configuration:
  - Top Reflector: 3” poly/lucite
  - Units: X number of poly or lucite/foil “units”
  - Bottom Reflector: 3” poly/lucite

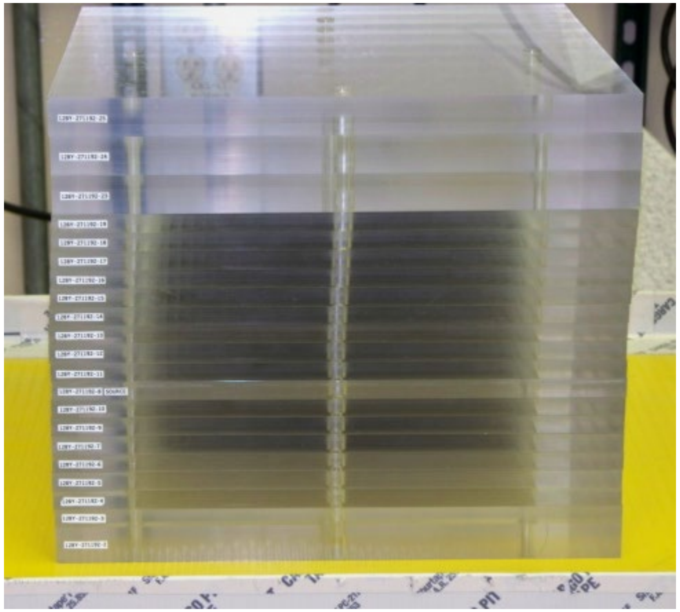
Initial Fuel Load



Take a neutron count after configuration is fully assembled.

Second Loading





Add one unit and take another neutron count after configuration is fully assembled.

Approach to Critical – Safety Rules

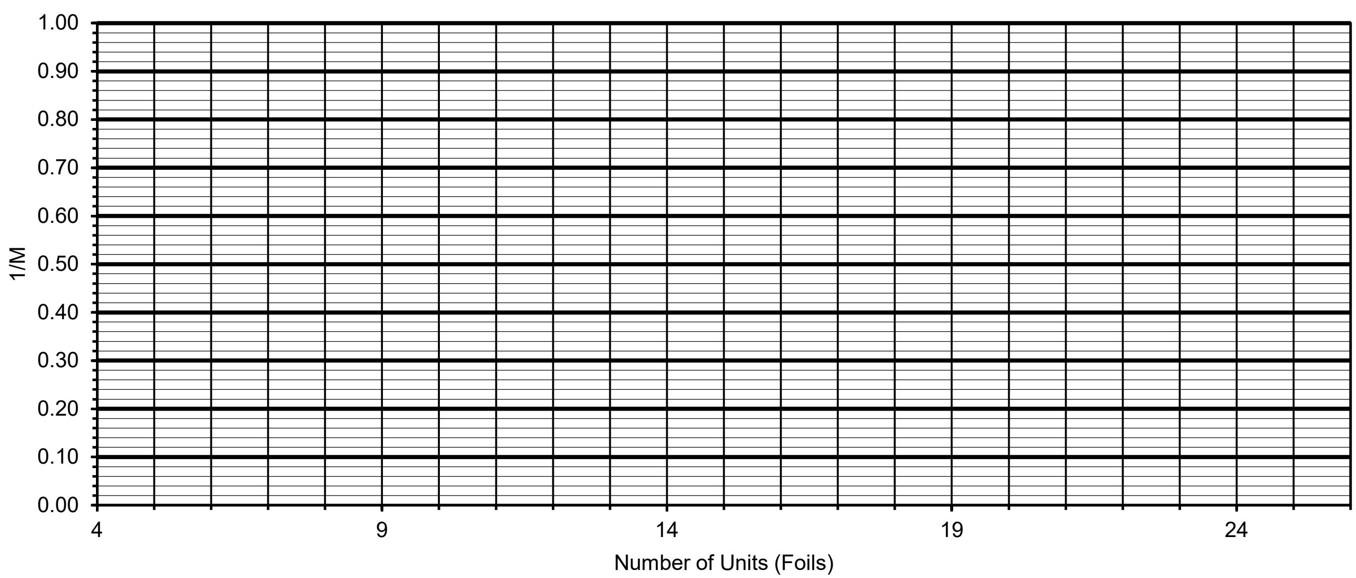
- Everyone is responsible for safety.
- Initial and second fuel loadings must be safe.
- Follow the 1/M critical approach curve.
- Limit hand-stacking (¾-rule).
- Limit rate of fuel addition (½-way rule).

Approach to Critical

- We do an approach to critical:
  - Start with only a few units (very safe, very subcritical)
  - By hand, on a cart (handstack)
  - Slowly add units to a single stack and use neutron detector to detect neutrons
  - Use simple calculations to estimate how many units we need to go critical
  - Stop well below our critical estimate!

Criticality Safety Workshop Data Sheet
and
Data Graph

Units	Counter 1	Counter 2	Counter 3	Counter 4	Total	M	1/M	Predicted Critical	1/2 Way	3/4 Rule

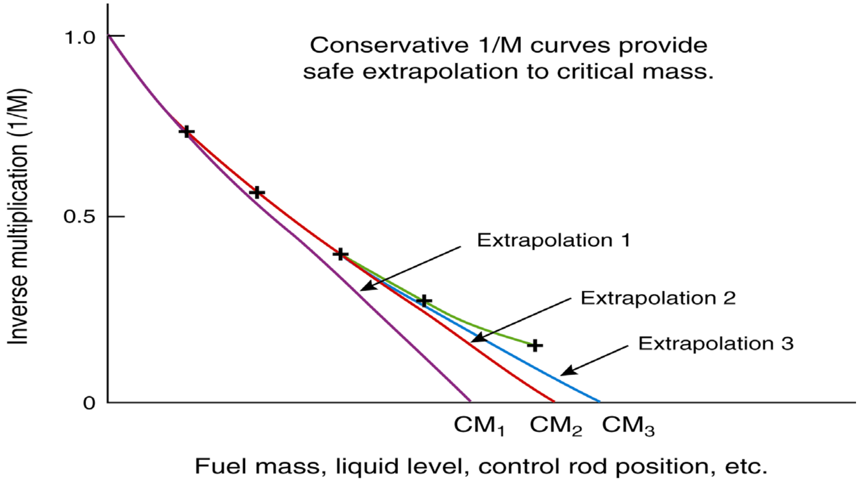


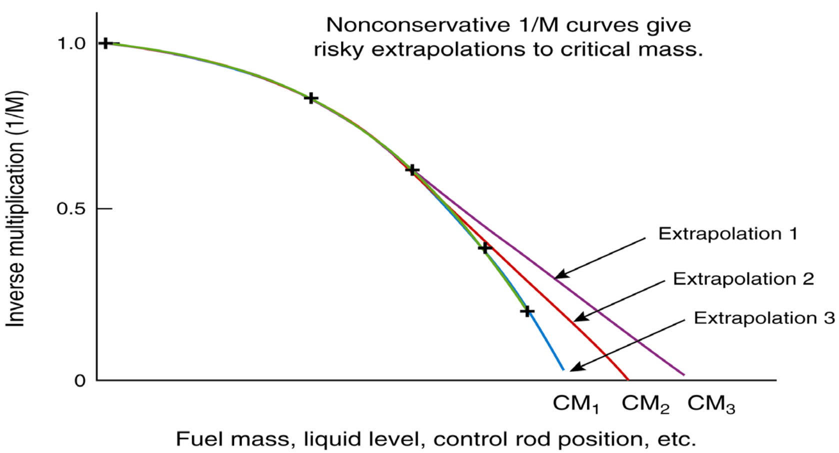
Approach to Critical Rules

- We have rules that we follow for worker safety when performing the approach to critical (1/M Approach to Critical)
  - The first and second configurations must be subcritical
  - We linearly extrapolate between the last two data points to estimate the critical configuration
  - Half-way rule: A single step can only go up to half-way to the critical estimate
  - Three-quarter rule: When handstacking (on the cart), we have to stop when we get to 75% (3/4) of the estimated critical mass, which corresponds to k_{eff}=0.90

Critical Mass Determination (1/M)

Step	Action
1	Determine base count rate
2	Add additional material (fuel, reflector, etc.).
3	Measure new count rate, and plot new 1/M.
4	Extrapolate to critical mass (1/M) = 0.
5	Determine safe addition for next step (based on ¾- and ½-way rules).
6	Repeat steps 2-5 to approach critical.





Approach to Critical Rules

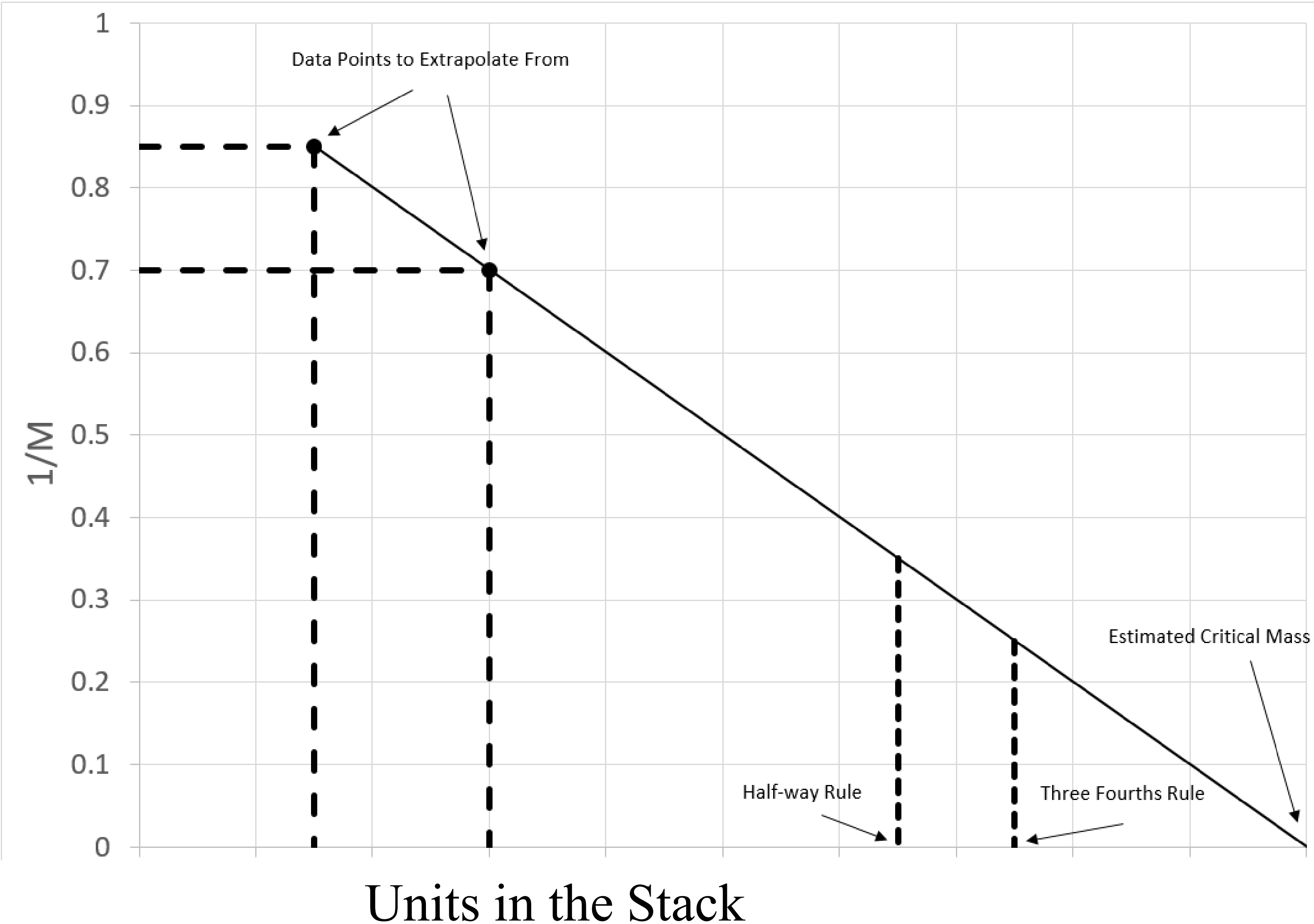
- Half-way rule:

(# units in assembly + # units expected critical)/2

- Three-quarter rule:

units expected critical *0.75

Approach to Critical Rules



Relative Multiplication

$C_0 = \varepsilon S M_0 \Omega$

$C_1 = \varepsilon S M_1 \Omega$

where

C is count rate

ε is the efficiency of the detector

S is the neutron source (n/sec)

M_0 is the initial multiplication (4 foils)

Ω is the solid angle

M_1 is the multiplication for 5 foils

$$\frac{C_0}{C_1} = \frac{\cancel{\varepsilon}\cancel{S}M_0\cancel{\Omega}}{\cancel{\varepsilon}\cancel{S}M_1\cancel{\Omega}} = \frac{M_0}{M_1}$$

NCSP
NUCLEAR CRITICALITY
SAFETY PROGRAM

Module 4
Part 2: Remote Approach to Critical Using the Planet/Comet Assembly

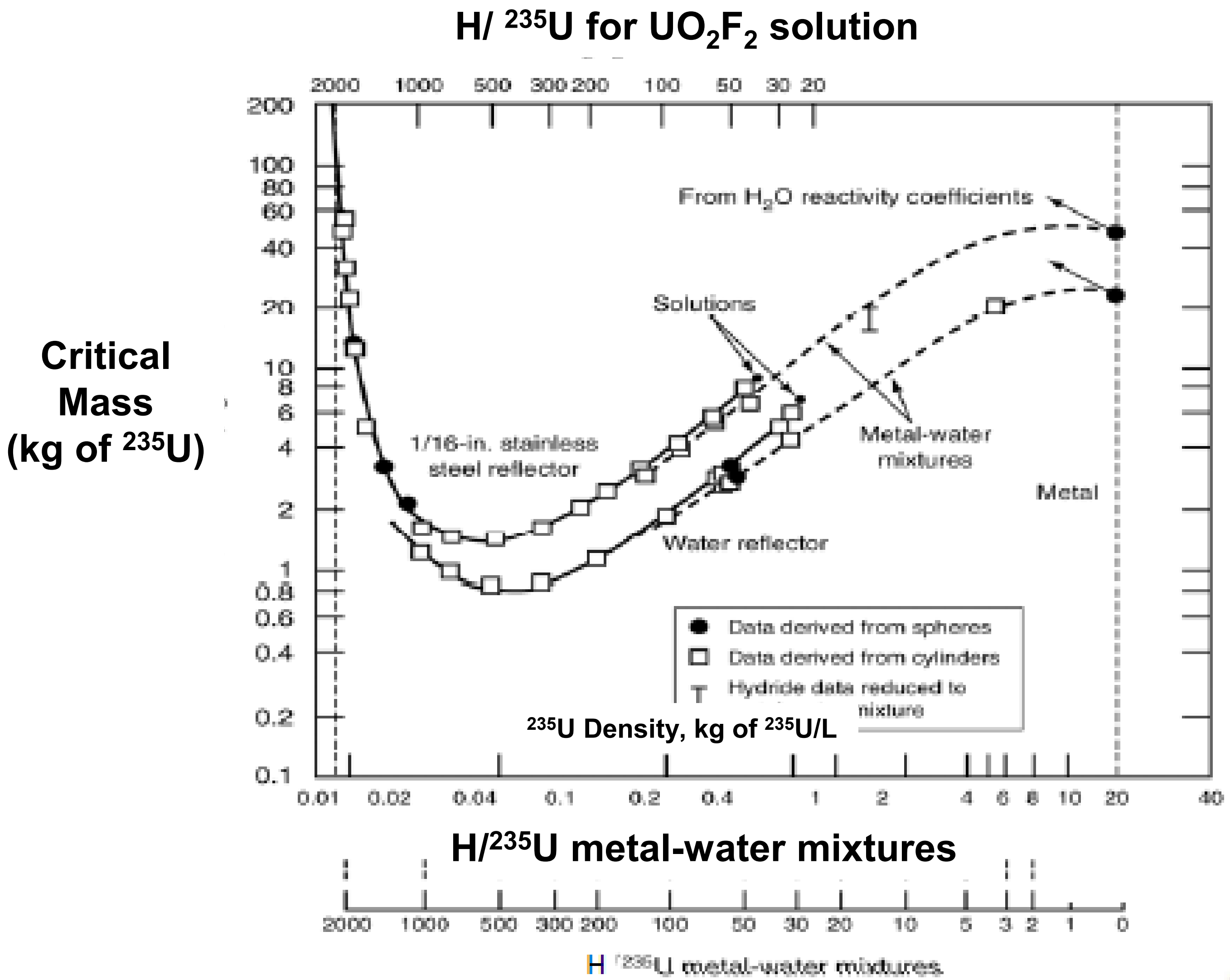
NCERC
NATIONAL CRITICALITY EXPERIMENTS RESEARCH CENTER
OAK RIDGE
National Laboratory
Sandia
National
Laboratories
Lawrence Livermore
National Laboratory
Los Alamos
NATIONAL LABORATORY

Approach to Critical

How do we continue once the Handstack limit is Reached???

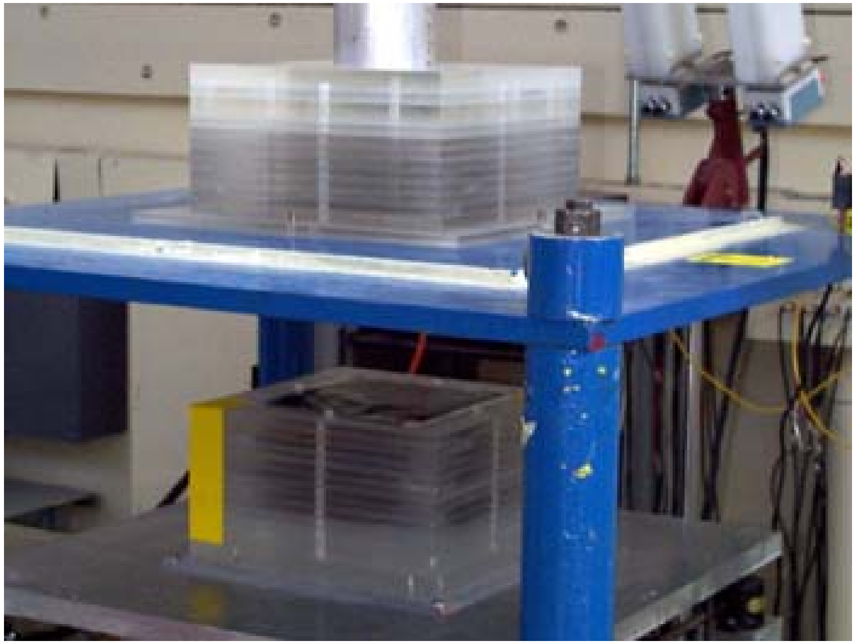
- Once we know what the limit is, put that portion on a moveable platform
- Put the additional units on a stationary platform
- Make certain the two stacks are well separated
  - What is “well separated”?
- Bring the two stacks together remotely
- Continue to add units to the stationary platform – eventually go critical!
- But where could we find such a machine or machines???

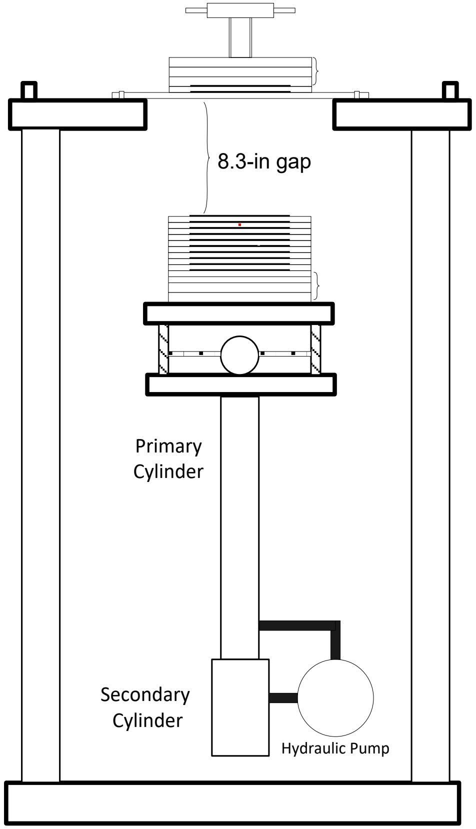
Critical Masses of Homogeneous Water-Moderated U(93.2) Spheres



Planet Critical Assembly

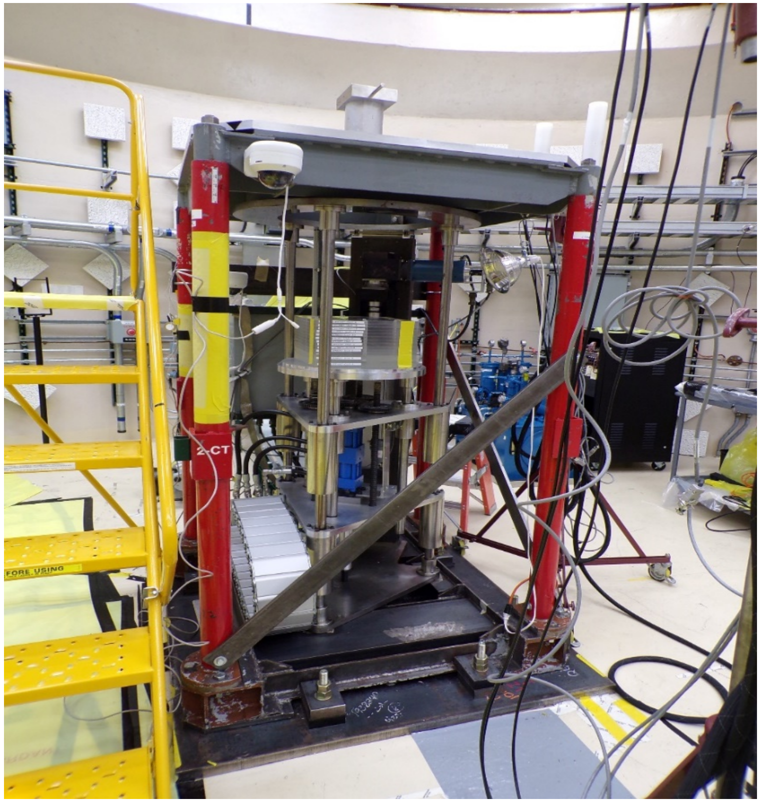
- Planet is a "light-duty," general-purpose, vertical-lift assembly machine.



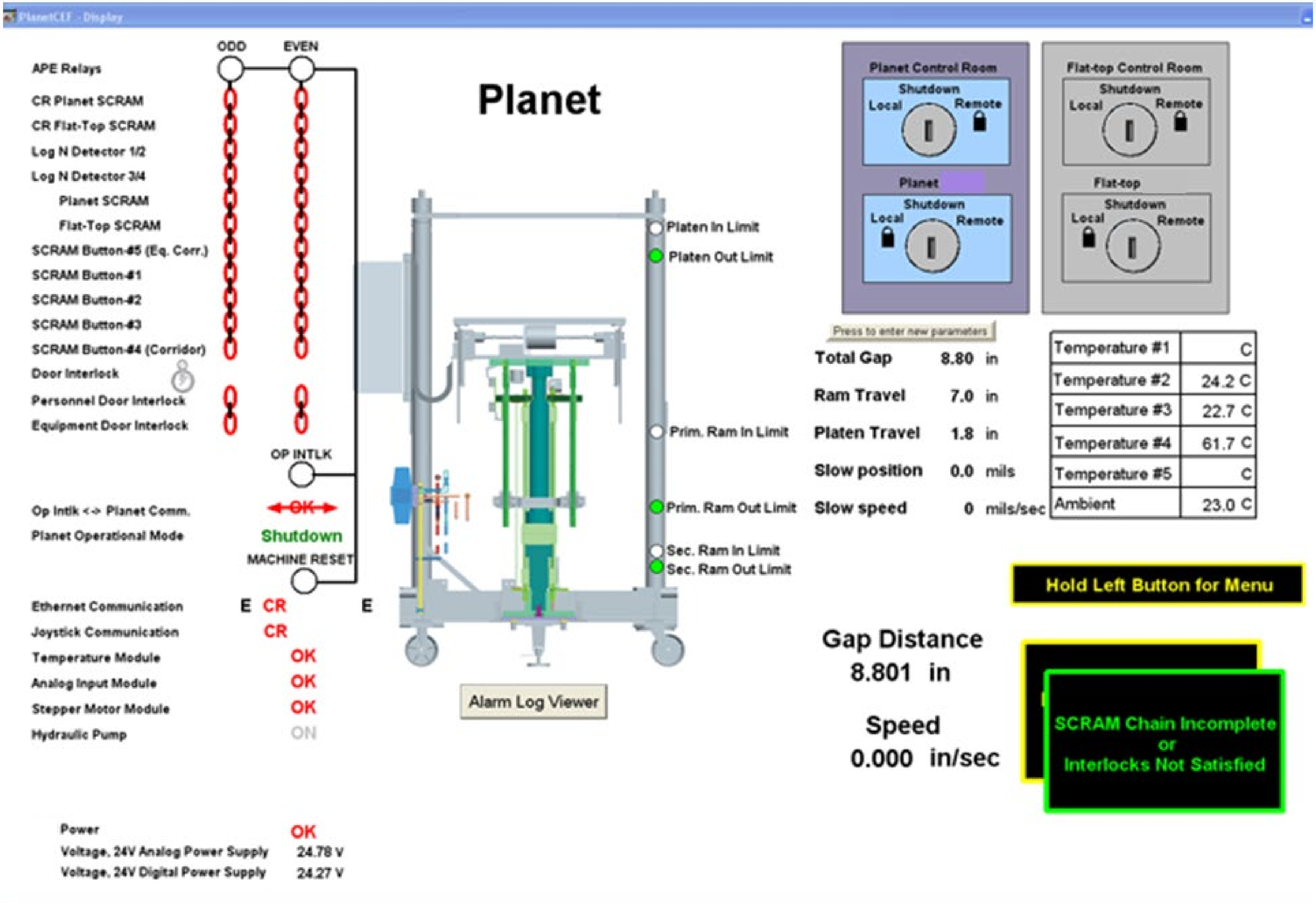


Comet Critical Assembly

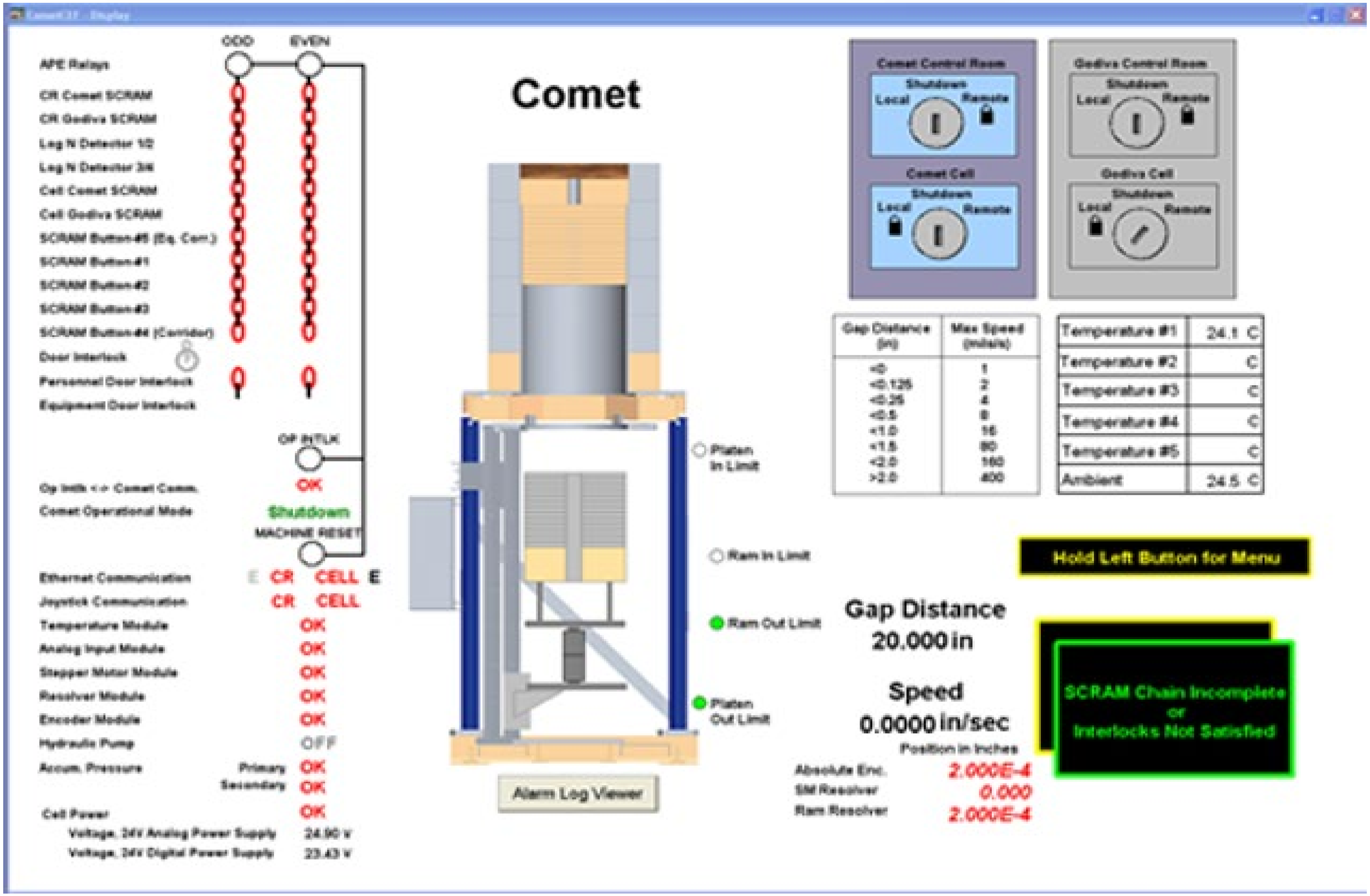
- Comet is a "heavy-duty," general-purpose, vertical-lift assembly machine.



Planet Control Panel Display



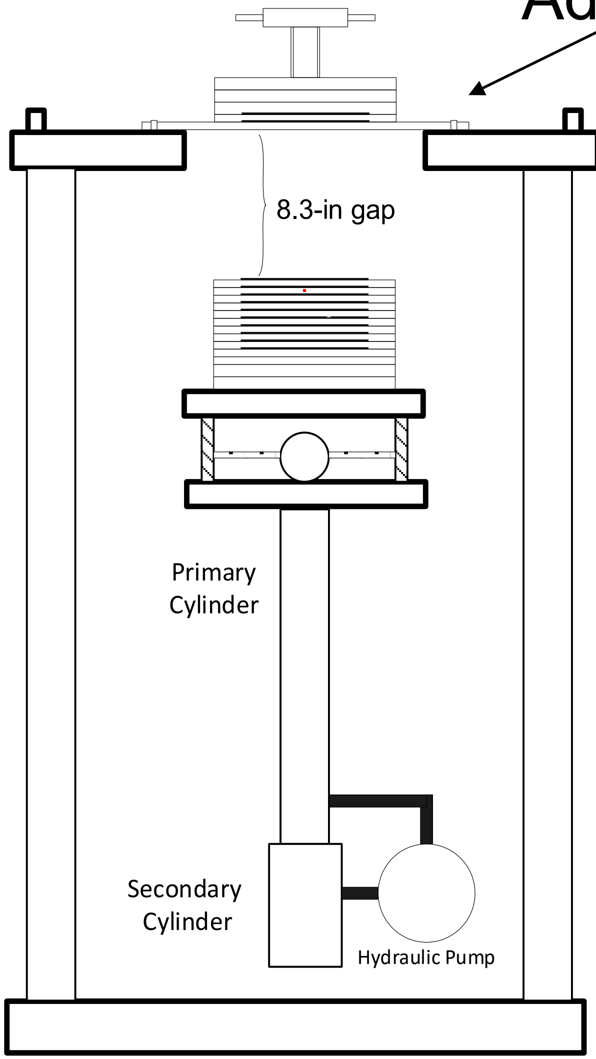
Comet Control Panel Display

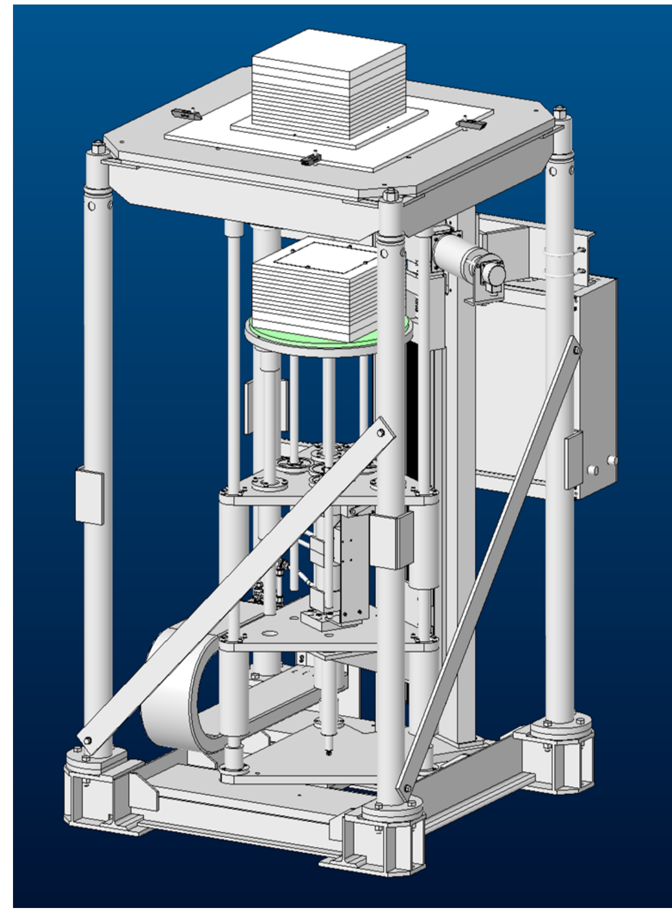


Initial Fuel Loading during Transition to Remote Operations

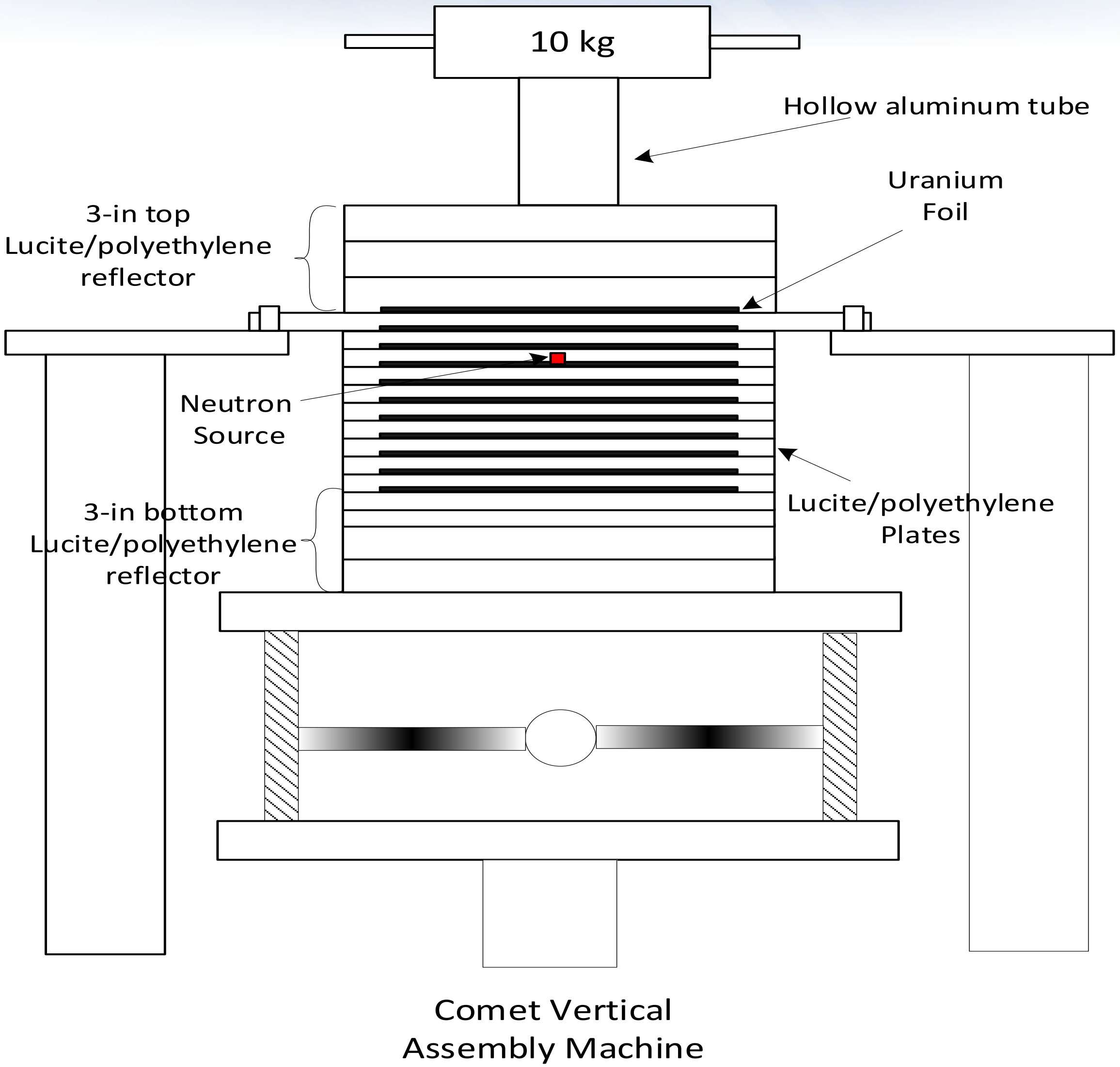
Add Units Here

Never more than the hand-stack limit (3/4 rule) on either of the two platforms during fuel loading.

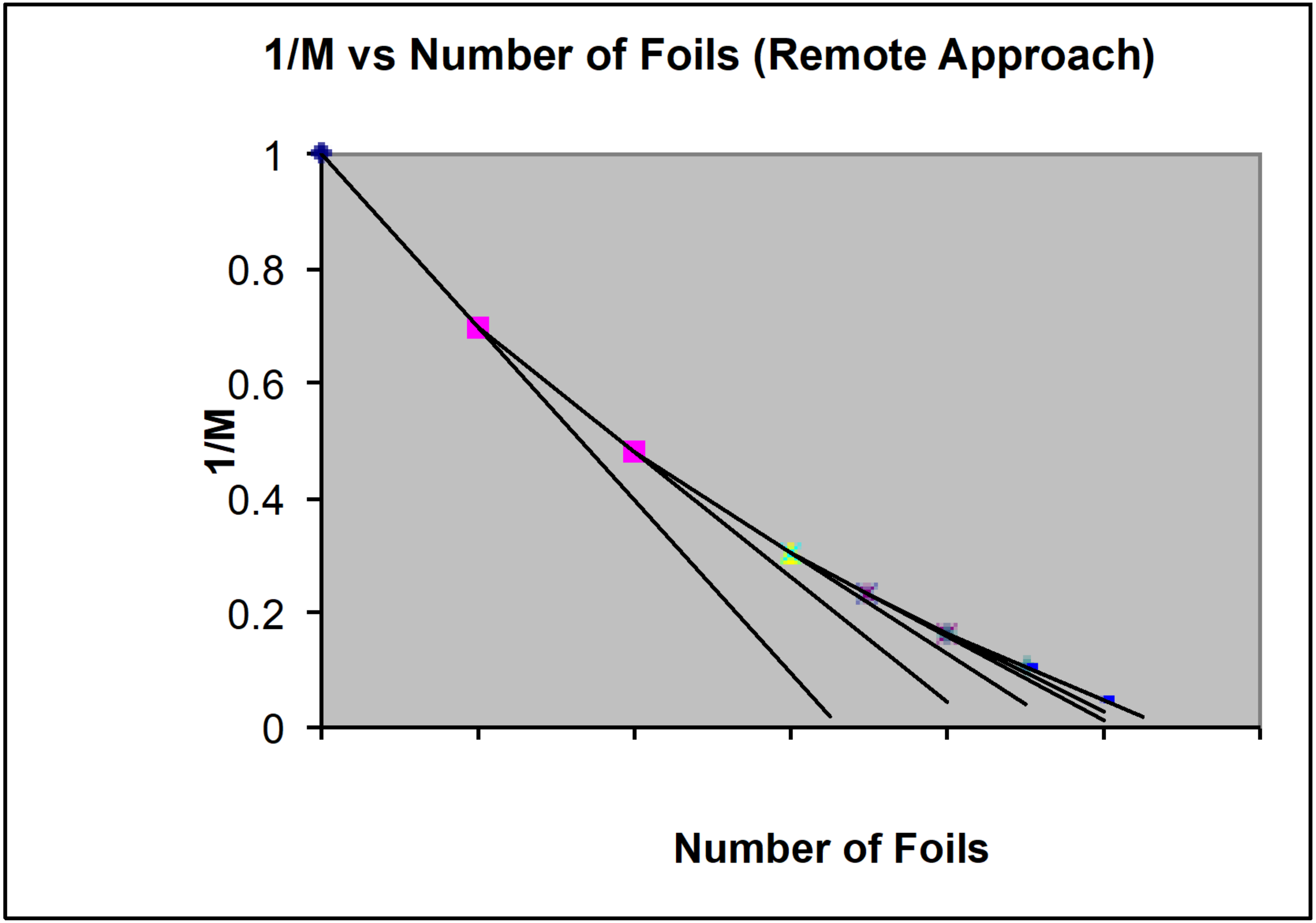




Planet during Remote Operation



Remote 1/M



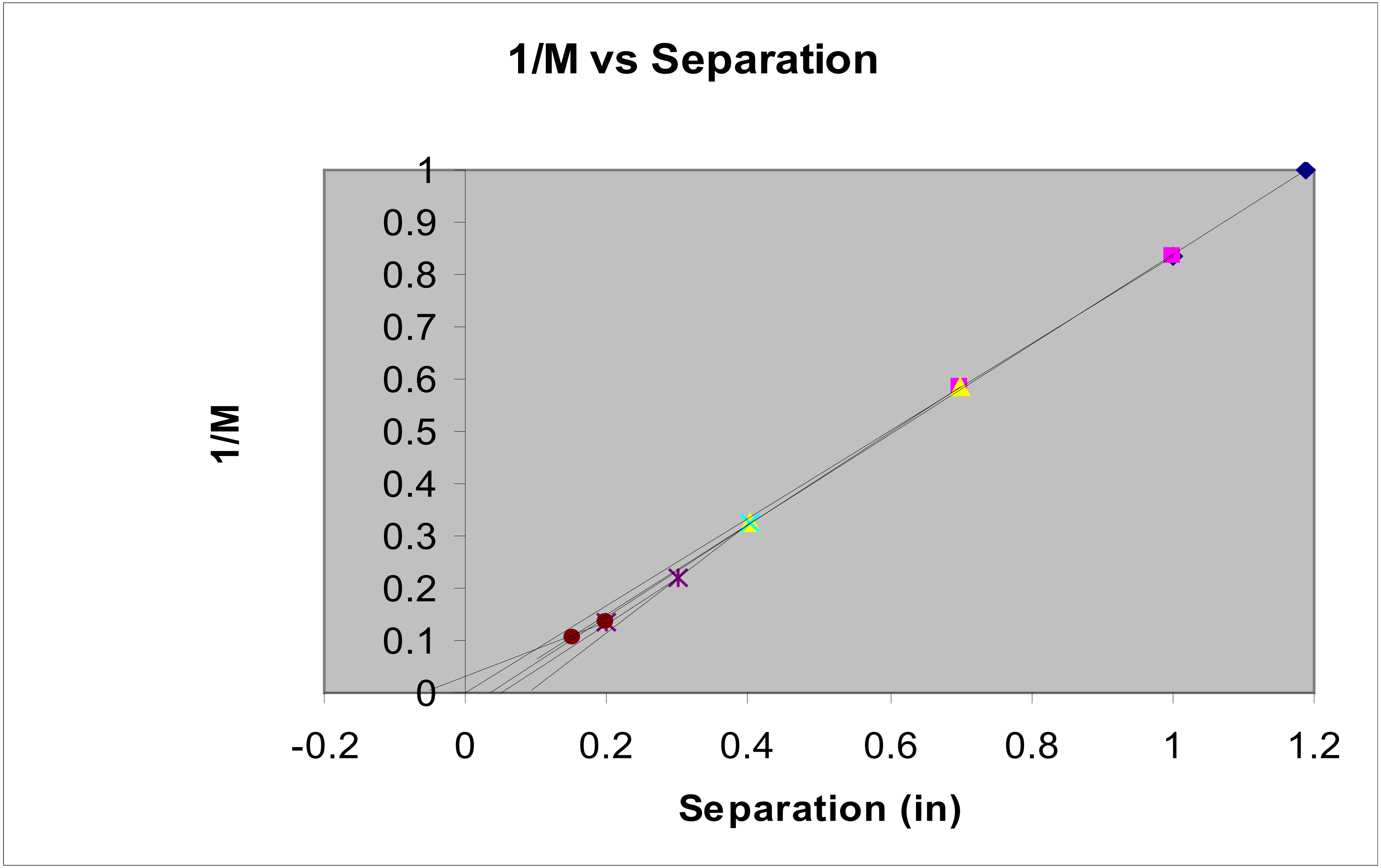
1/M vs Number of Foils (Remote Approach)
1
0.8
0.6
0.4
0.2
0
1/M
Number of Foils

Final Approach to Critical

When the next unit addition will be more than 1/2 way to critical:

- add next Unit,
- use separation distance as unit for 1/M approach, and
- continue until completely closed.

1/M Using Closure



Find Critical

- Repeat until it is apparent that this unit will go critical.

- Add enough reactivity to be on a positive period.

- Find delayed critical.

- Shim with spacers, adjust the stacking, or use partial foils to adjust the excess reactivity.

- Perform measurements as outlined in the Experiment Plan.

Inhour Equation (Class Foil Experiment)

$$\rho(\$) = \frac{l}{\beta_{eff} * T} + \sum_{i=1}^{6} \frac{\beta_i / \beta_{eff}}{1 + \lambda_i T}$$

where

$\rho(\$)$ is the reactivity in dollars

β_{eff}/l is the Rossi-α at delayed critical

β_{eff} is the effective delayed neutron fraction for the system

T is the reactor period

β_i/β_{eff} is the relative abundance for ^{235}U for each of the six groups from thermal fission

λ_i is the decay constant for ^{235}U for each of the six groups from thermal fission

l is the neutron lifetime of the system

Parameters Needed for the Inhour Equation

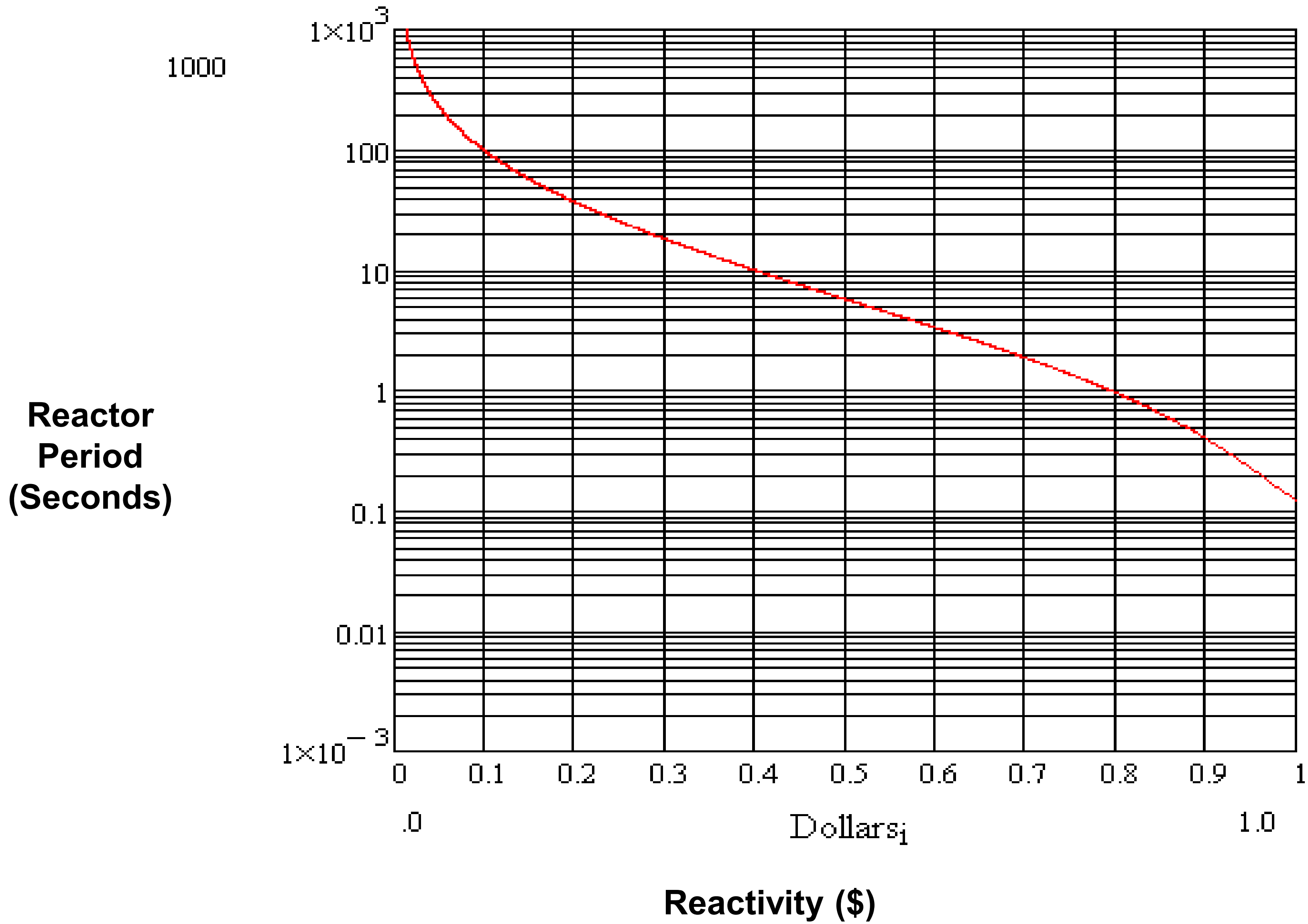
For the Criticality Safety Class Foils Experiment:

$$\alpha(DC) = \beta/l = 200\ s^{-1}$$

Decay Constants and Yields for ^{235}U from Thermal Fission[1]

Group Index, i	Decay Constant λ_i s^{-1}	Relative Abundance $a_i = \beta_i/\beta_{eff}$
1	0.0124	0.033
2	0.0305	0.219
3	0.111	0.196
4	0.301	0.395
5	1.14	0.115
6	3.01	0.042

Graphical Representation of the Inhour Equation for the Class Foil Experiment



References

1. R. R. Paternoster et al., "Safety Analysis Report for the Los Alamos Critical Experiments Facility (LACEF) and the Hillside Vault (PL-26)," Los Alamos National Laboratory repor, LA-CP-92-235, Rev. 4 (1998).
2. R. Brewer, D. Loaiza, and R. G. Sanchez, "Polyethylene Reflected and Moderated Highly Enriched Uranium System with Silicon," International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC/(95)03/II, HEU-MET-Therm-001.
3. G. R. Keepin, *Physics of Nuclear Kinetics,* Addison-Wesley Publishing Company, Inc., Reading MA (1965).

Benchmark Data for Class Foil Experiment

Uranium Metal Foils
9.0-in square by 0.003-in thick

93.19 wt% ^{235}U
5.43 wt% ^{238}U
0.26 wt% ^{236}U
1.13 wt% ^{234}U
Average Density: 17.25 g/cc

Lamination:
Two laminated sheets
10-in square by 0.003-in thick
Modeled as polyethylene (CH_2)
Average Density: 1.226 g/cc